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Distributed Fiber Optic Sensing for Homeland Security

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Introduction: The need to protect our borders and critical infrastructure, such as pipelines, power distribution, and transportation, has grown in importance over the last few years. To address this need, fiber optic sensing technology developed in the Optical Sciences Division at NRL for antisubmarine warfare applications has recently been adapted to homeland security applications. Ground-based seismic sensing applications have significantly different requirements than traditional underwater acoustic applications. As a result, new optical interrogation and signal processing techniques are needed. Border and critical infrastructure sensor systems must be able to monitor long lengths (several km to several 10's of km) with reasonable spatial resolution (5 to 100 m), and have sufficient seismic sensitivity to detect targets of interest. We have developed and recently field-tested a fiber optic distributed seismic sensor system capable of meeting these requirements and report on some initial observations below.

Fiber Optic System Description: The system concept for a border monitoring application is shown in Fig. 1. The sensor is a standard commercial off-the-shelf (COTS) optical fiber cable buried in the ground along the perimeter to be monitored. Seismic activity in the ground couples to the buried cable and induces a strain in the optical fiber within the cable. The optical interrogation system developed at NRL simultaneously monitors the entire fiber length (currently up to 5 km) for time-varying changes in strain. The interrogation system segments the optical fiber into sequential spatial channels of a fixed length (currently 10 m) as shown in Fig. 1. With this spatial aperture, the system is capable of detecting very low signal-level induced strains in the fiber. One of the goals of these field tests was to equate the strain resolution capabilities of the optical system with real-world seismically induced strain levels observed in a buried optical cable.

The interrogation and signal processing system shown in Fig. 1 is connected to one end of the optical cable, which would typically be placed in a secure location. The interrogation system houses the electro-optics components that optically interrogate the sensor cable and demodulate the return signal to recover the seismically induced strain. The signal processing system monitors activity along the entire perimeter and includes a real-time display and data archival functions.

Field Test Results: The system has been tested at two different locations in the southwestern United States using optical cables buried from less than one foot deep to as much as four feet deep. Several fiber optic cable designs, with different fiber protection schemes and cable armoring, have been tested. As might be expected, different burial depths and cable designs yielded different levels of sensor sensitivity, but in general, all tested configurations performed satisfactorily.

Many test scenarios were run, including individuals walking and running, digging, and a variety of vehicles both on road and off. In one of the walking test scenarios, an individual started at the buried cable and walked perpendicular to the cable. When he reached the end point, he stomped his foot ten times to mark the end of the test. The envelope of the time series data for this test from one 10-m spatial channel is shown on the top of Fig. 2. Each spike in the plot corresponds to a footfall of the walker. The bottom half of the plot shows the spectrogram of the time series envelope for the same segment of time. The cadence of the walker is clearly visible in the spectrogram and is seen to lower in frequency as the walker slowed down near the end of the test.

In one installation, a section of the cable was buried roughly 3 m from the edge of a paved roadway. During our testing, a caravan of seven Humvees drove up the road and stopped near the 350-m mark. The progress of all seven vehicles along the array can be seen in Fig. 3, which is a waterfall display of the seismic energy detected on the first 150 10-meter spatial chan-

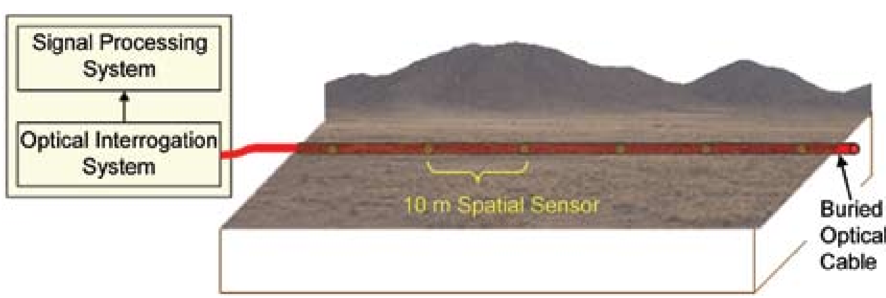

FIGURE 1
Buried fiber optic distributed seismic sensor border monitoring concept.

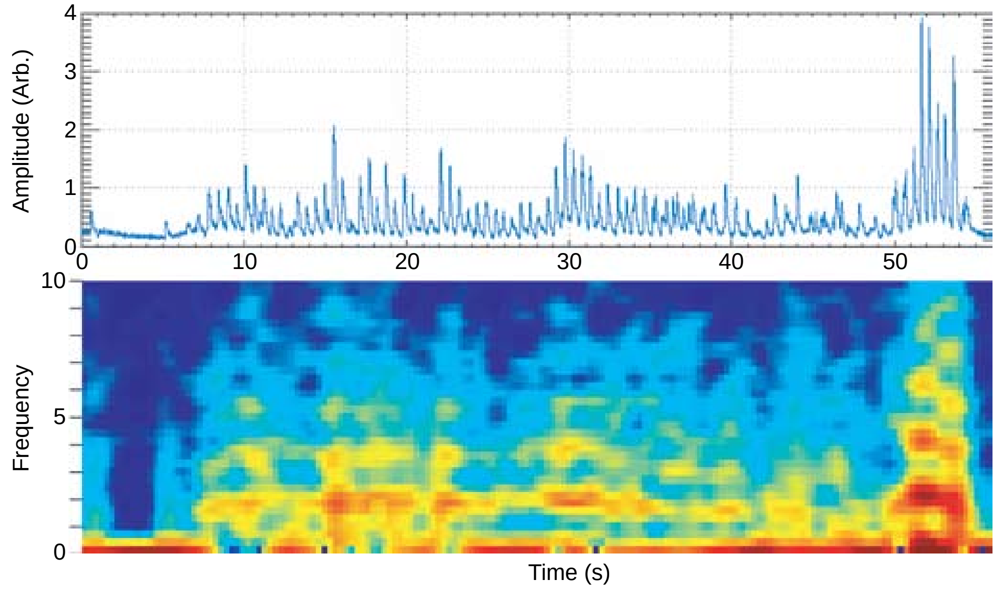

FIGURE 2
The envelope of the time series of a person walking perpendicular to the cable is shown in the top plot. The bottom image shows the spectrogram (time-frequency plot) of the time series envelope above.

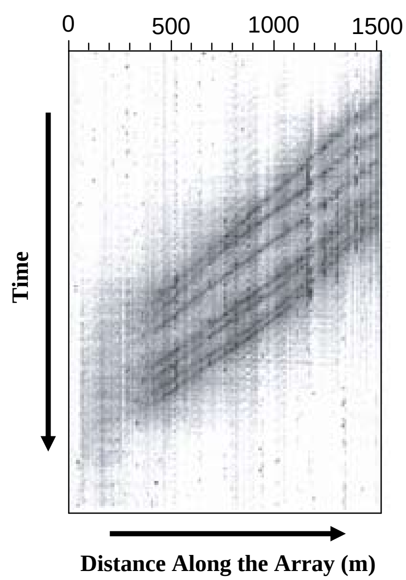

FIGURE 3
Band power waterfall display of a caravan of seven Humvees driving up the array from the distal end.

nels (1.5 km total span). The signal intensity is color-coded from white to black, covering a 50-dB variation in signal level.

Closing: The fiber optic system developed is capable of transforming a standard single mode optical fiber in a COTS cable into a sensitive seismic sensor. The achieved sensitivities and detection capabilities are in line with the requirements for trip wire border monitoring and homeland security applications. The current system can resolve 10-m spatial regions and can interrogate up to 5-km perimeters. This system provides a new, unique sensing capability to better protect our borders and critical infrastructure.

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